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THE STAVE FALLS POWER DEVELOPMENT OF WESTERN CANADA POWER COMPANY, LIMITED.

BY R. F. HAYWARD, M.CAN.SOC.C.E.

(To be read before a Monthly Meeting of the Society,
October 7th, 1915).

History.—Though the first settler entered the Stave Lake district over thirty years ago, access was so difficult that only a few families stayed on the land, supporting themselves by hand logging in the immediate vicinity of the river.

To all practical purposes the valley of the Stave remained in primitive state until the formation of the Stave Lake Power Company in 1899, and to this day the Upper Stave River has been partly explored.

The first application for a water record at Stave Falls was in 1899, for the right to use a flow of 2,150 c.f.s. (61 cu. m. s.) for development of power.

The Stave Lake Power Company established a camp and saw at Stave Falls, opened up a wagon road from the C.P.R. at Ruskin on the Fraser River, made surveys of the Lake site, established a gauge for recording the flow of the river, and built a concrete log sluice dam as the first work in the construction of a power plant.

In June, 1909, the property of the Stave Lake Power Company, Limited, was purchased by the Western Canada Power Company,



Limited, and development on a much larger scale than had been contemplated by the pioneer company, was commenced.

Application was made in the fall of 1909 to the Dominion Government for storage rights on Stave Lake, involving the flooding of some 8,000 acres (3,200 hectares) of low lying land. After considerable delay, caused by legal difficulties which had arisen between the Dominion and Provincial Government in respect to the administration of water lying within the Railway Belt—the applica-

tion was granted.

The Western Canada Power Company, Limited, now has the right to store water in Stave Lake, to develop power at Stave Falls to a capacity of over 50,000 horse-power, and to develop a second power site at the mouth of Stave River to an equal capacity. Besides having the right to make use of the water for the development, the company is the riparian owner of practically the whole margin of the water from the upper end of the lake to the mouth of Stave River.

Active work on the construction of a plant designed for an ultimate capacity of 50,000 horse-power was commenced at Stave Falls early in 1910, and a standard gauge railway, six miles long, was built to transport machinery and materials from Ruskin to the power site.

The first installation, consisting of two 9,000 k.w. units, was put in commission in January, 1912, and by the commencement of 1913 contracts had been entered into which made it necessary to complete the Stave Falls plant to its ultimate capacity of 50,000 horse-power, without delay, and to provide for the construction of a second plant at the mouth of the Stave River within a few years time. Contracts were placed for the third and fourth 9,000 k.w. units early in 1913.

Location and Topography.—Stave Lake is a body of water about nine miles long and one and a half miles wide, lying thirty miles east of Vancouver, and forming an important part of the basin of the Stave River, which from its glacier source in the mountains to its junction with the Fraser River at Ruskin is about sixty miles long.

The whole of the watershed is formed by the granite mountains of the Coast Range; the lower part, including half the lake and the Lower Stave River, which is twelve miles long, has a maximum altitude of about 4,000 feet (1,200 metres) and is heavily timbered; the upper part consists of rugged mountains rising high above the timber line, and carrying perpetual snow and small glaciers. Mount Baldy, the principal peak of the watershed, standing near

CHARGE: \$

the head of the lake and rising to an altitude of over 6,000 feet (1,800 metres) when viewed from the river or lake on a fine day, forms one of the most beautiful pictures that can be found in British Columbia.

The drainage area is between 400 and 450 square miles (1,000 to 1,200 square kilometres) but nothing definite is known about this, as the greater part of the upper watershed is unsurveyed, unexplored, and is only known in parts by a few hunters, prospectors and timber cruisers.

A survey of such an area is no small undertaking and involves a serious expenditure of time and money.

The horizontal benches that can be seen on the north side of Burrard Inlet, at Point Grey, at Mission, at points along the Fraser River, and again at Port Angeles, on the south side of the Straits of San Juan de Fuca, give evidence that at some period the waters of the Straits of Georgia were some 250 feet (75 ms.) above the present sea level, held back, perhaps, by a great glacier. At this period, all the valleys to the north of the Fraser River were filled with glaciers, which built up terminal moraines to about this level.

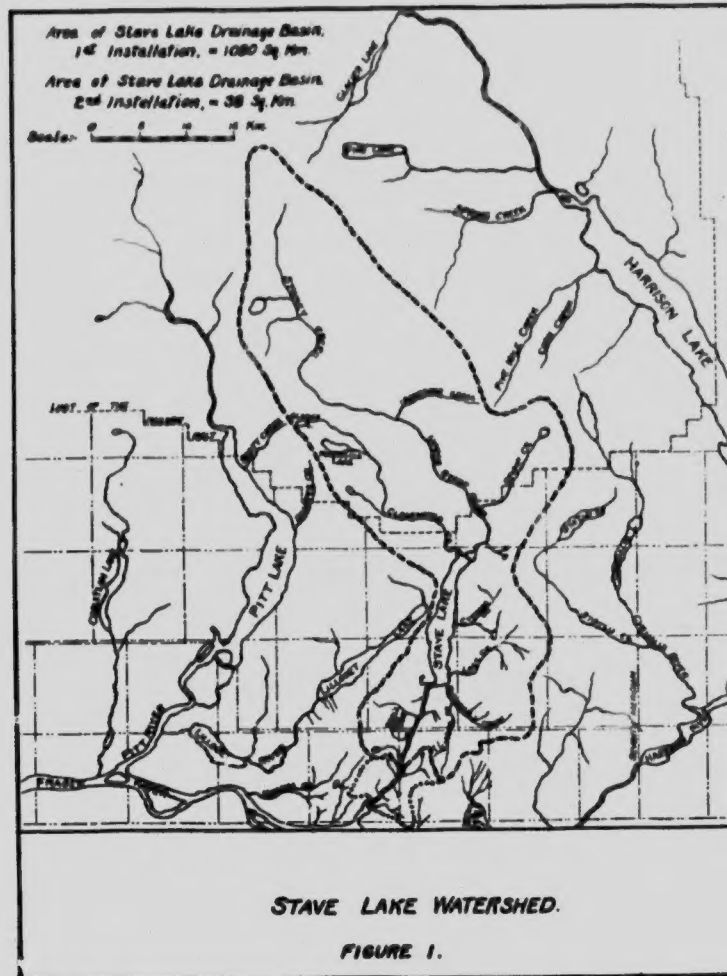
The glacier of the Stave must have terminated at Hatzic Prairie, where now can be clearly seen the line of the terminal moraine across the valley five miles wide. As the glacier receded this moraine formed a natural dam which held the lake to an elevation of about 300 feet (90 ms.) above sea level. The benches along the lower Stave River show that this lake extended nearly to the mouth of the river, and it is clear that during this period vast deposits of clay, glacial meal, and sand were laid down in the still waters, while boulders were deposited promiscuously by floating ice.

Later on as the silting process raised the level of the lake an outlet was found over the bench which can be seen about one mile north of the Canadian Pacific Railway bridge over the Stave River. The water found its outlet at a point where the silt deposit, being in a comparatively thin layer on the top of a granite bluff, was easily eroded, and once started it continued to flow over the rock, gradually washing out a gorge 160 feet (48 ms.) deep in the solid granite instead of cutting its way through the deep layers of comparatively soft deposit only a few hundred feet away. As the rock was cut away by the action of the water, the level of the lower part of the lake was reduced by successive stages, leaving several well defined benches in the valley below the lake.

Between the Fraser River and the lake, in a distance of twelve miles, there are four points where in the same manner the action of the elements has produced such perfect hydraulic fills that the

floods of ages have found it easier to penetrate the solid ground than nature's earth works.

Add to these the natural dams formed by logs, driftwood, silt deposit, and the beaver dams with which this district abounds.



and engineers will find enough natural hydraulic works on Stave River to afford much profitable study.

In its natural state the water level of the lake at low stands about 230 feet (70 ms.) above mean sea level, and in about 15 feet higher than this. If the level of the lake were

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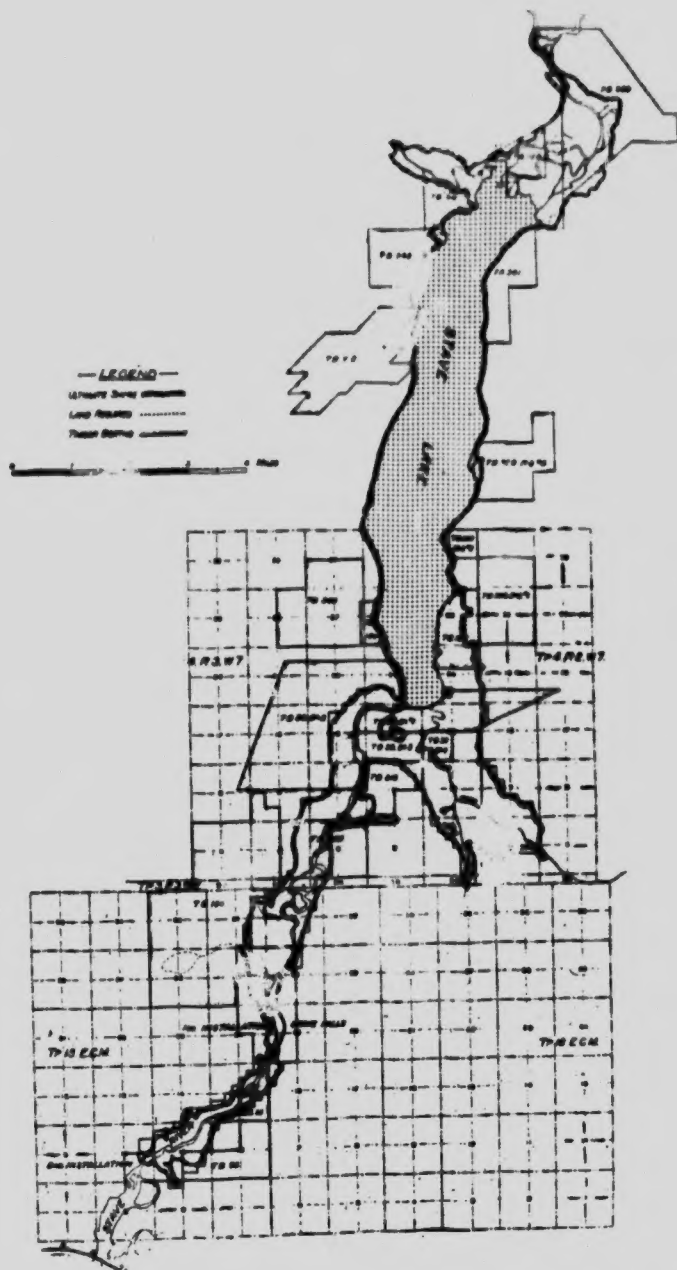


Fig. 2.

120 feet, the water would find an outlet into the ancient channel through Hatzic Prairie.

The present works are designed to raise the level thirty (9 ms.) above low stage, and at some future date they may be to raise it forty feet (12 ms.), but any further increase in elevation would not be feasible from a financial standpoint.

The river from the lake to Stave Falls is about 250 feet (7 ms.) wide and nearly constant in width, except where, at the falls, it flows between two rock ledges only 100 feet (30 ms.) apart.

The natural fall from the lake to the head of the falls is 14 feet (4.3 ms.)—the whole of this fall occurring in a series of rapids extending over one and a half miles of river. The rest of the seven miles of the river between the lake and the falls is navigable and runs from fifteen to thirty feet deep.

At the falls the river is separated by an island, into two channels. The intake dam, power house and tailrace are built in the westerly channel, while the easterly or main channel is separated by a log sluice dam. Another old channel closed by log jams and beaver dams many years ago, is situated about a quarter of a mile to the east of the falls. This channel, known as the Blind Sluice, is to be utilized for flood discharge, when the works are completed.

From still water above the head of the falls to the pool below, there was a drop of 80 feet (24 ms.) with a further fall of 45 feet (13.5 ms.) in the half-mile of river immediately below. At this point the river runs over boulders in a continuous series of rapids until it debouches through the rocky gorge, in which a lower plant is to be built, into the tide flats at Ruskin.

The total fall available for power purposes between the lake to which the lake is to be raised by the works now under construction, and the low water of the Fraser River is about 250 feet (75 ms.) of which 120 feet (36 ms.) will be utilized in the present works.

The fall of 130 feet (40 ms.) available below the upper plant can be developed by the construction of a dam in the rock gorge which will form a reservoir about $3\frac{1}{2}$ miles long, and will raise the water to the tailrace level of the upper plant; or it may be more economical to make the development in two power houses each operating under 65 ft. head (19.8 ms.). Investigations with respect to this lower development are now in progress.

Surveys.—The original surveys were made to an assumed datum approximately 30 feet above mean sea level. In January 1913, the Western Canada Power Company, Limited, adopted the metric system for its development work, and all surveys made since are referred to mean sea level datum.

Table I. gives the elevation of the principal features and structures, both on the old and new surveys:—

TABLE I.
ELEVATIONS AT STAVE FALLS AND VICINITY.

	On old Survey Datum in feet.	On new Survey Datum in meters.
Mean Sea Level	29	0
Mean Tide, L. W. Fraser at Ruskin	24	1.53
H. W. Fraser River at Ruskin	6	7.01
C.P.R. Bridge at Ruskin	1	9.15
Tail Water Stave Falls, at Power House....	110	42.38
Bed of River at Damsite	170	60.66
Stave Lake, Extreme Low Level	197.5	69.04
“ “ “ High Level	214.5	74.23
“ “ “ Normal Level (River discharge), Mean Flow	201.7	70.33
Flow Line at Intake Dam, January, 1914...	215	74.38
“ “ “ “ “ “ 1915...	220	75.90
“ “ “ “ “ “ 1916...	230	78.95
“ “ “ “ “ Ultimate	240	82.00

Water Supply.—Prior to 1911, when the Dominion Government organized a hydrographic survey of the Railway Belt, very little reliable information existed in respect to the precipitation, runoff, and flood discharge of the drainage areas of British Columbia, and engineers who were called upon to investigate or carry out new projects, were forced to base their estimates on assumptions, that in many cases were little better than mere guesses.

The only data that was at all reliable was to be found in the records of the few companies who had actually carried out, or were carrying out, developments in this region.

It was fortunate that the development of the Stave Falls project was delayed for a number of years after its inception, and that during these years some valuable water records were obtained. It is still more fortunate that the records obtained during the past four years have shown that the assumptions made on the basis of the information available in 1909 have proved to be fairly correct.

To intelligently lay out a hydro-electric development the following information in respect to the watershed should be available:—

(1) The precipitation at the point of diversion for a series of years.

(2) The relation between the precipitation at the point of diversion to the average precipitation over the whole watershed.

(3) The effect of snow fields and glaciers in regulating the flow of the river.

(4) The effect of forest cover, and underground storage, in maintaining the flow through the winter months, and preventing the formation of ice.

(5) The relation of the runoff to the rainfall.

(6) The effect of the natural storage of the lakes in the watershed in modifying the flood discharge, and the amount of maximum flood discharge possible if the modifying influence of the lakes were removed.

(7) The amount of storage required to utilize the maximum flow of the river.

(8) The cost of obtaining storage to various amounts, and the maximum it is possible to develop.

(9) The economical point of development taking into consideration the cost of the works, and the amount of water available.

Rainfall.—A rain gauge was established in 1909 at Stave Falls, and the records from this are the only measured records of rainfall on the watershed. Arrangements are being made to establish a second rain gauge at the head of the lake, but there seems to be no satisfactory way to record snowfall without an attendance at the station—and for five months in the year the precipitation at this point is in the form of snow.

The records obtained from the Stave Falls gauge compare closely with those obtained at the Government station at Nicomen, that it has been possible to compute from them the rainfall at Stave Falls for the past twenty years, which is given in the following table:—

TABLE II.

ANNUAL PRECIPITATION AT STAVE FALLS.

Year.	Inches.	Cms.	Year.	Inches.
1893 ..	98.1	249.3	1905 ..	71.5
1894 ...	107.2	272.6	1906 ..	75.5
1895 ..	83.1	210.9	1907 ..	63.9
1896 ..	86.3	219.4	1908 ..	69.1
1897 ..	79.7	202.4	1909 ..	76.1
1898 ..	76.8	195.1	1910 ..	90.7
1899 ..	87.0	220.9	1911 ..	73.3
1900 ..	87.0	220.9	1912 ..	67.8
1901 ..	83.2	211.3	1913 ..	78.5
1902 ..	77.3	196.2		—
1903 ..	86.8	220.3	Mean	80.7
1904 ..	75.4	191.5		—

It will be noted that with the exception of 1894, the year of the great flood on the Fraser River, the variation of rainfall in any year is no greater than 22 per cent. above or 21 per cent. below the mean for twenty years.

It will be observed that low rainfall years do not always come singly, from which it follows that to utilize a mean flow of several years would involve storage extending over a period of two and possibly three years. This is not financially feasible even though it were physically possible.

Consequently the year of lowest runoff must be taken as the basis for development. The year of lowest rainfall is not necessarily the year of lowest runoff—for instance the rainfall in 1907 was 63.9 inches (162.3 cms.)—but the lowest runoff occurred in 1911, with a rainfall of 73.3 inches (186.2 cms.). This is probably due to a difference in summer temperature, causing a greater melting of the snowfields in 1907 than in 1911.

The mean monthly precipitation at Stave Falls is given in the first column of Table III. The highest precipitation comes in November, and the lowest in July and August.

During January, February, and part of March, the whole of the watershed is usually under snow, and from October to May the precipitation on the higher levels is all in the shape of snow, except for one or two days in October and November, when heavy warm rains fall over the greater part of the watershed to cause the rapid melting of fresh snow.

Runoff.—A gauging station was established on the Stave River at a point about 2,000 feet above the falls in 1901, and the gauge heights were recorded daily from 1905 until October, 1911, when the closing of the dam rendered the gauge useless.

While this station was not rated as completely as might have been desired, it appears that such gaugings as were made were carried out carefully.

Gauges to record the level of the river were also set up at the foot of the lake, and half way between the lake and the falls. These were read daily for nearly two years, and the records have supplied much information in respect to the flow of the river.

A new gauging station about half a mile below the falls was established in the summer of 1910, and rated by a long series of current meter measurements.

The measurement of the higher flood discharge has been difficult to secure, as the river velocities in flood are too great for current meter work, but it has been possible to calculate the discharge through the sluiceways of the dam by weir formulæ with reasonable accuracy.

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inches.	Cms.
71.5	181.7
75.5	191.7
63.9	162.3
69.1	175.6
76.1	193.3
90.7	230.3
73.3	186.2
67.8	172.2
78.5	199.5
80.7	204.9

The collecting and checking of all these records have a large amount of careful work, the principal results of which are set forth in Table III.

TABLE III.
TABLE OF RUNOFF AND PRECIPITATION DATA.

	Mean Monthly Precipitation at Stave Falls, in inches	Units in c. f. s. sq. mile of Drainage Basin			Runoff as % of Precipitation at Stave Falls	% of Precipita- tion at Stave Falls remaining as Snow Storage
		Mean Monthly Runoff	Minimum Monthly Runoff	Lowest Year of Runoff 1911		
Jan.	8.87	6.16	3.20 ('07)	4.42	81 %	80 %
Feb.	7.39	5.97	2.19 ('11)	2.19	84 %	77 %
March	5.84	5.01	1.66 ('12)	5.17	99 %	62 %
April	3.95	7.62	4.05 ('12)	5.66	215 %	
May	5.06	11.24	7.78 ('05)	12.62	256 %	
June	3.35	13.11	10.01 ('05)	13.75	436 %	
July	1.80	10.10	6.37 ('12)	11.59	577 %	
August	2.87	6.09	4.18 ('05)	5.53	245 %	
Sept.	5.23	8.70	3.71 ('01)	8.25	186 %	
Oct.	8.15	9.48	2.57 ('07)	4.48	134 %	27 %
Nov.	13.41	16.59	5.43 ('05)	9.84	138 %	23 %
Dec.	9.32	7.51	5.99 ('12)	7.38	93 %	68 %

Mean Annual Precipitation 75.4 inches.

Mean Annual Runoff 9.0 cu. ft. per
sq. mile of
area.

Ratio of Mean Annual Runoff to Mean Annual Precipitation .

NOTE.—The above figures are based upon an estimated drainage area of 100 sq. miles and are subject to modification on the completion of proper watershed measurements. Figures for precipitation and runoff are based on records extending over a period of 10 years and from May 1905 to September 1913 inclusive.

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results of which are

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% of Precipitation at Stave Falls remaining as Snow Storage	% of Total Snow Storage melted during each Summer Month
80 %	
77 %	
62 %	
	7.6 %
	17.0 %
	32.6 %
	29.7 %
	8.5 %
	4.6 %
27 %	
23 %	
68 %	

inches.

cu. ft. per sec. per
q. mile drainage
area.
precipitation.... 1.61

age area of 450 square
per watershed surveys.
ending over part of 1901

The first column in this table gives the mean monthly precipitation at Stave Falls in inches.

The second, third and fourth columns give respectively the mean monthly runoff, the minimum monthly runoff, and the monthly runoff for 1911, (the lowest year) in cubic feet per second per square mile of drainage basin, the area of the drainage basin being assumed at 250 square miles.

The fifth column gives the monthly ratio of runoff to precipitation, and the sixth and seventh give an indication of the effect of snow storage upon the runoff.

The mean annual runoff is very nearly 4,000 cu. feet per second (114 cu. ms. per second), and in the lowest year on record (1911), the mean annual runoff was 3,400 sec. feet (97 cu. ms. per second).

The mean annual runoff measured in cubic feet per second per square mile of watershed is perhaps the most important figure in relation to other developments. If this figure were known for a few more of the watersheds of British Columbia, the runoff of any drainage area could be predicted fairly closely.

From the data at present available it appears that the mean annual runoff on the Coast Range from Portland, Oregon, to Prince Rupert, ranges from 4.5 to 10 cubic feet per second per square mile of watershed (50 to 110 litres per sq. kilom.), generally tending towards the lower figure for watersheds on Vancouver Island, and the State of Washington, and towards the higher figure for the Western slopes of the Coast Range of British Columbia.

In the Stave Lake watershed the annual runoff per square mile cannot be known until the drainage area is finally determined, but upon the assumption of 450 sq. miles (1,165 sq. kiloms.) the mean annual runoff comes out at 8.9 cu. ft. per second per square mile (98 litres per sec. per sq. kilom.), and the minimum annual runoff (1911) at 7.6 (83 litres per sec. per sq. kilom.). If the drainage area proves to be only 400 square miles (1,036 sq. kilom.) these figures will be increased to 10 cu. ft. and 8.5 cu. ft. per second per square mile (110 and 94 litres per sec. per sq. kilom.).

The relation between mean annual runoff and the mean annual precipitation is important, but cannot be compared with similar ratios obtained from eastern watersheds, because the precipitation is only known in this case for one point in the drainage basin.

For the Stave Lake drainage area the ratio between the mean annual runoff (assuming 450 sq miles of area) and the mean annual precipitation at Stave Falls is 1.61, which indicates how much greater the precipitation must be over the upper watershed than is measured by the gauge at Stave Falls.

Table IV. gives the same data as Table III. in the system.

The relation between daily precipitation, temperature and runoff is shown in Fig. 3, which gives for the months of November and December, 1911, not only the observed runoff charge, which is modified by the natural lake control, but the calculated runoff and the river discharge with the lake maintained at constant level.

TABLE IV.

	Mean Monthly Precipitation at Stave Falls in c.ms.	Units in litres / sec. / sq. kilom. of drainage		
		Mean monthly runoff.	Minimum month- ly runoff.	Lower runoff
Jan.	22.54	67.4	35.20	4
Feb.	18.77	65.3	24.09	2
March	14.83	54.8	18.26	5
April	10.03	83.4	44.55	6
May	12.85	123.0	85.58	13
June	8.51	143.4	110.11	15
July	4.57	110.4	70.07	12
Aug.	7.28	66.5	45.98	6
Sept.	13.28	95.1	40.81	9
Oct.	20.70	103.7	29.37	4
Nov.	34.06	181.3	59.73	10
Dec.	23.67	82.1	65.89	8

Mean 1911.

1 inch = 2.54 c. ms.

1 cu. ft. per sec. per sq. mile = 11 litres per sec. per sq. kilom. approximately.

The Water Year.—For the Coast Range of British Columbia the water year should be taken from October 1st to September 30th because the end of September is usually the time when the

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151.25

127.49

60.83

90.75

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108.24

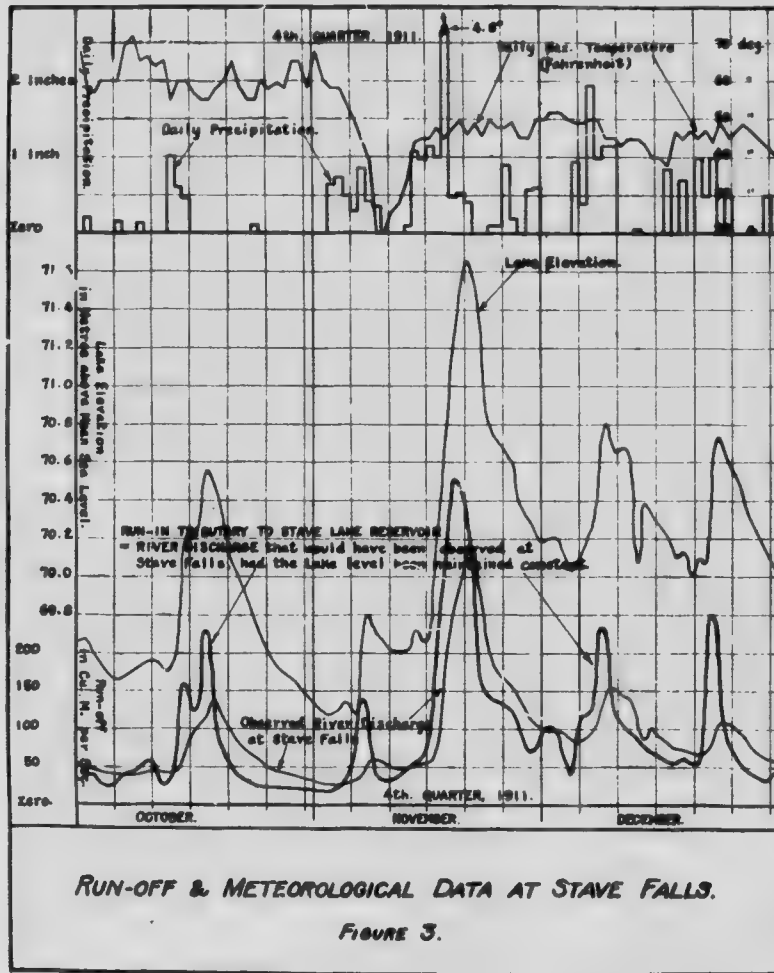
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British Columbia
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area holds the least quantity of water, that is to say, the snow fields, glaciers, lakes and underground waters are drained to their lowest about that time.

The fall rains commencing after October 1st replenish the snow fields and saturate the ground under the forest cover. The



heavy rains of November which are often very warm, melt a large amount of fresh snow, and finding the storage ground saturated run off rapidly and produce the highest freshets.

Towards the end of December the ground is saturated, the lake is filled up, and the river flow is about equal to the mean flow of the year.

January, February and March bring snow which does and the runoff is supplied partly from the underground partly from the natural storage of the lake, which gradually in level. Although the temperature stays about zero (Fahrenheit) times for a week at a time, the inflow of warm underground is sufficient to prevent the formation of any ice on the river in its natural state.

By the end of March the ground waters have drained and the lakes are at lowest level, and the runoff is the smallest of the year, the river flow going as low as 750 cu. ft. per second (63.7 cu. ms. per sec.) for a few days at a time. The lowest mean monthly runoff is 2,250 cu. ft. per second (63.7 cu. ms. per sec.) and the lowest monthly runoff of record (Feb. 1911) was 985 cu. ft. per second (28 cu. ms. per sec.)

In April the snow begins to melt on the lower levels, and in June and July are the months of greatest snow runoff. During this period it is seldom that any high freshet occurs, but throughout the year the river is uniformly high, gradually rising to a maximum at the end of June, and slowly falling off through July, August and September.

With comparatively unimportant variations the cycle of the river follows year after year.

Flood Discharge.—Stave Lake in its natural condition has a drainage area of approximately 11 square miles (28 sq. kilometers) large enough to exert a very great modifying influence on the discharge of the lower river. The conditions of the river between the lake and the falls are such that the hydraulic gradient of the river is nearly constant at all stages of flow. For every foot of rise in the river at Stave Falls, a corresponding foot of rise in the lake, consequently when a freshet flows into the lake from the Upper Stave River, the lake level gradually rises and the outflow gradually increases until a maximum outflow is reached with the lake level from 12 to 15 feet above low stage, after which the lake and river slowly fall.

A rainfall of 1 inch (or 1 cm.) over the whole drainage area is equivalent to 3.5 ft. (or 42 cms.) in depth of the lake level; the natural storage of the lake will modify a flood to the extent of holding back the equivalent of 4 inches (10.2 cms.) of water over the whole drainage area—or a flow of 48,000 cu. ft. (1,360 c. ms. per sec.) for 24 hours.

The highest observed flood discharge occurred in 1909, and reached a maximum of 37,400 cu. ft. per second (1,020 c. ms. p. sec.) and on October 13th, 1913, a flood reaching a maximum of 36,000 cu. ft. per second (1,020 cms. per sec.) occurred.

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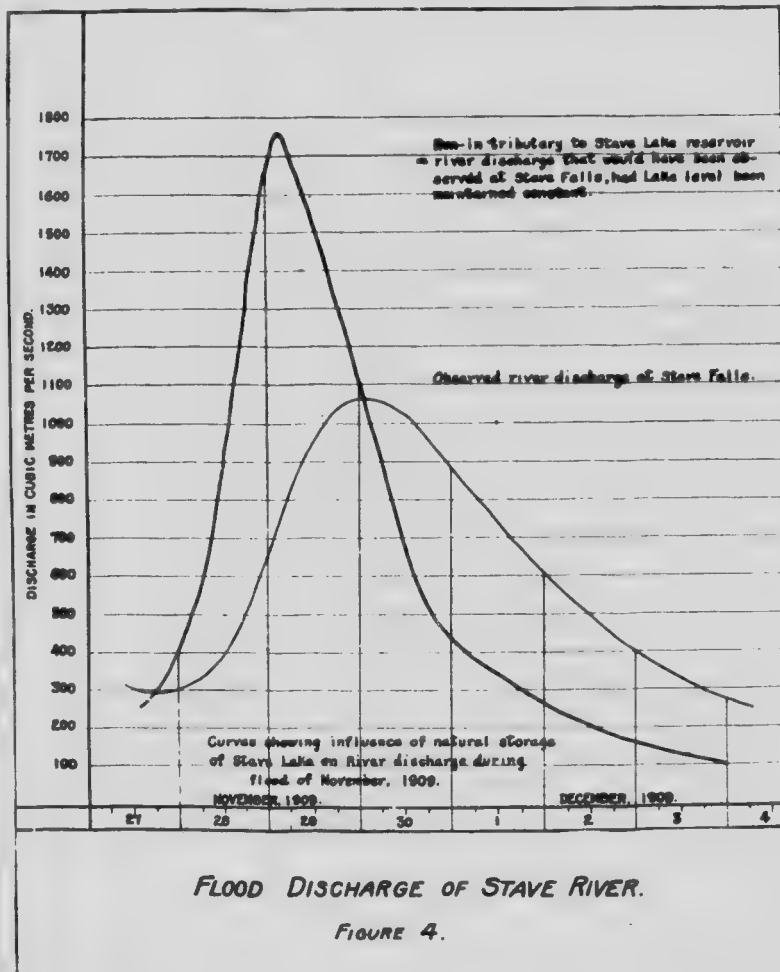
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urred in November, t. per second (1.060 od reaching a maxi- er sec.) occurred.

The effect of the lake on the flood control is shown very clearly by the diagram Fig. 4, which shows the observed rise and fall of the flood of November, 1909, and the discharge that would have obtained if the lake had been maintained at constant level. From this it can be seen that the maximum inflow was 63,000 cu.



ft. per second (1,780 cu. ms. per sec.) or nearly twice as great as the observed maximum discharge. This corresponds to a flood runoff of 140 cu. ft. per second per square mile (1,530 litres per sq. kilom.) of watershed, on the assumption of 450 sq. miles of drainage area.

The spillway capacity of a dam must be based upon figures, and not upon the observed flood, as a heavy flood occurs when the reservoir was full.

In the designs of the dams at Stave Falls a flood discharge of 100,000 cu. ft. per second (3,000 cu. ms. per sec.) is being provided for.

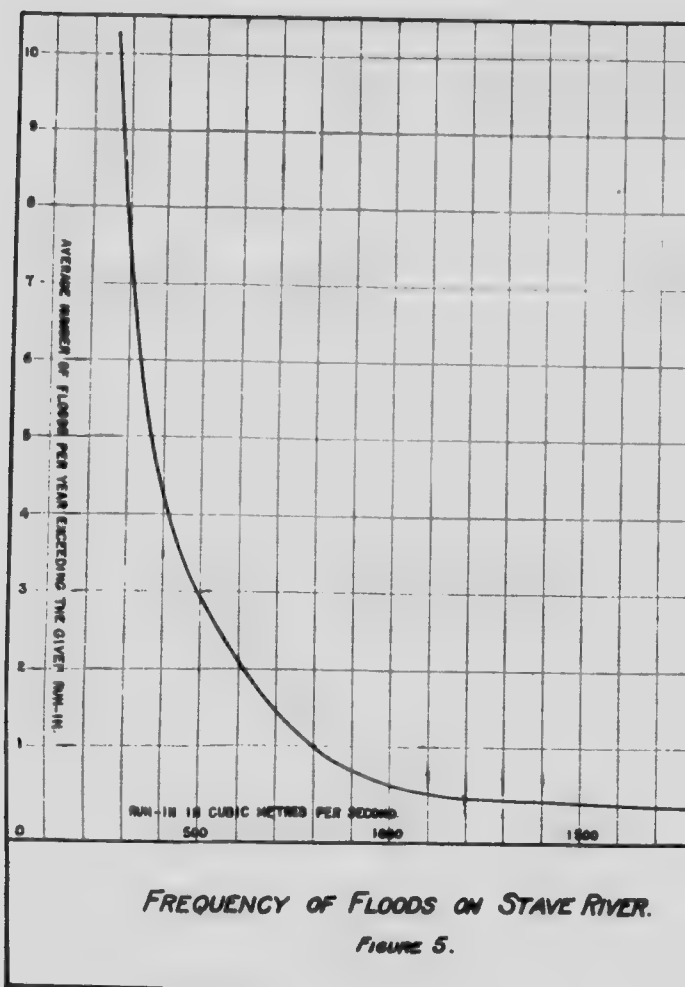


Figure 5 is a diagram showing the average number of floods during the year that the flow into the reservoir—that is, runoff, exceeds any given amount. It is based on record

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heavy flood might

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number of times
—that is, the total
on records of the

flood seasons of ten years, and gives some sort of guide to the probabilities of freshets.

The control of these floods is a matter that has required very serious consideration. The lake in its natural state is a very perfect flood controller—but when turned into a reservoir it ceases to be a flood controller unless the water is allowed to rise some eight to ten feet above the normal high water operating level.

A dam with a spillway not exceeding 300 to 400 feet in length would control the flood discharge in the same way as the lake in its natural state, because the lake would have to rise and so store flood water before the spillway could discharge to its full capacity, and so the maximum flow over the spillway would be much smaller than the maximum run into the reservoir. This would form a perfect automatic control, but at the sacrifice of valuable storage capacity.

If the spillway was infinitely long, the lake could not rise, and the maximum discharge over the spillway might be equal to the maximum run-in. With a spillway 1,000 feet long or more, a discharge equal to the maximum run-in would have to be handled whenever a flood came when the reservoir was full.

But sooner or later storage capacity becomes too valuable to sacrifice for flood control, and the reservoir is held for operating purposes to the highest level for which the structures are safe.

Consequently, sluice gates or automatic flash boards must be provided to keep the level constant, and these must be made of sufficient capacity to take care of the biggest run-in possible.

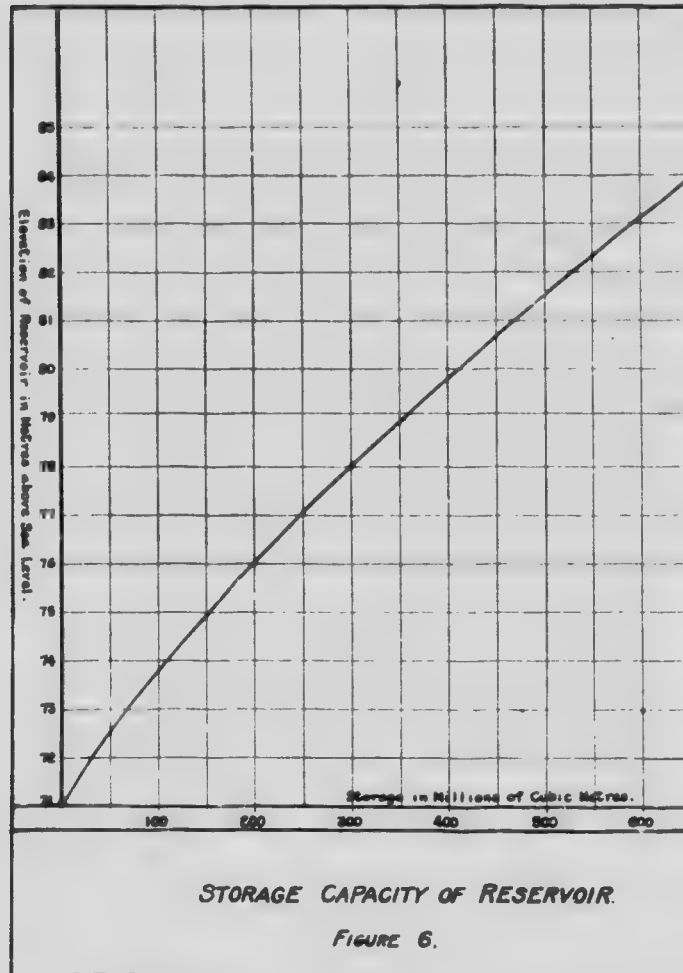
Artificial Storage.—Figure 2 is a plan of Stave Lake, and the adjacent low-lying land which will be flooded by the construction of a storage dam at Stave Falls. The heavy black line shows the area submerged when the water is raised 40 feet above natural low water level (elev. 82 m.). The natural area of the lake is 11 square miles (28 sq. kiloms.). The area at the 240 ft. (82 m.), contour is 24 sq. miles (62 sq. kiloms.).

Figure 6 shows the storage capacity of the reservoir at various heights. In order to determine what storage capacity should be provided in order to utilize the mean runoff of the watershed for the lowest year, viz., 3,400 c.f.s. (97 c. m. per sec.) in 1911, the following procedure was followed:—

A mass diagram was constructed from the runoff records, and from this diagram it was found by the usual method what mean flow could be utilized for varying storage capacities. Curves were then constructed for each of the years from 1905 to 1913 inclusive (Fig. 7) showing the mean flow per square mile of drainage area as

abscissae, and the storage required in acre feet per square ordinates.

Figure 8 is a series of similar curves plotted to metric units. The general shape of these curves shows clearly the limit to which storage does not increase the mean flow.



Taking the curve for 1911—the mean runoff for the 3,400 cu. feet per second (97 c. ms.), or 7.6 c.f.s. per sq. mile of watershed (81 litres sec. per sq. kilom.).

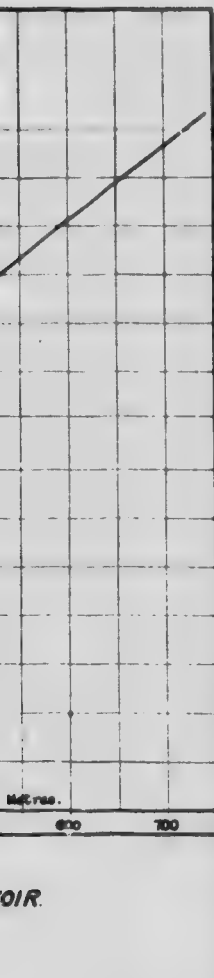
To utilize the whole of this would require a dam of elevation 236 feet (81 ms.), having a storage capacity of

per square mile as

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acre feet (456,000,000 cu. ms.)—or about 800 acre feet per square mile (381,000 cu. ms. per sq. kilom.) of drainage area, which is nearly 15 per cent. of the annual runoff.

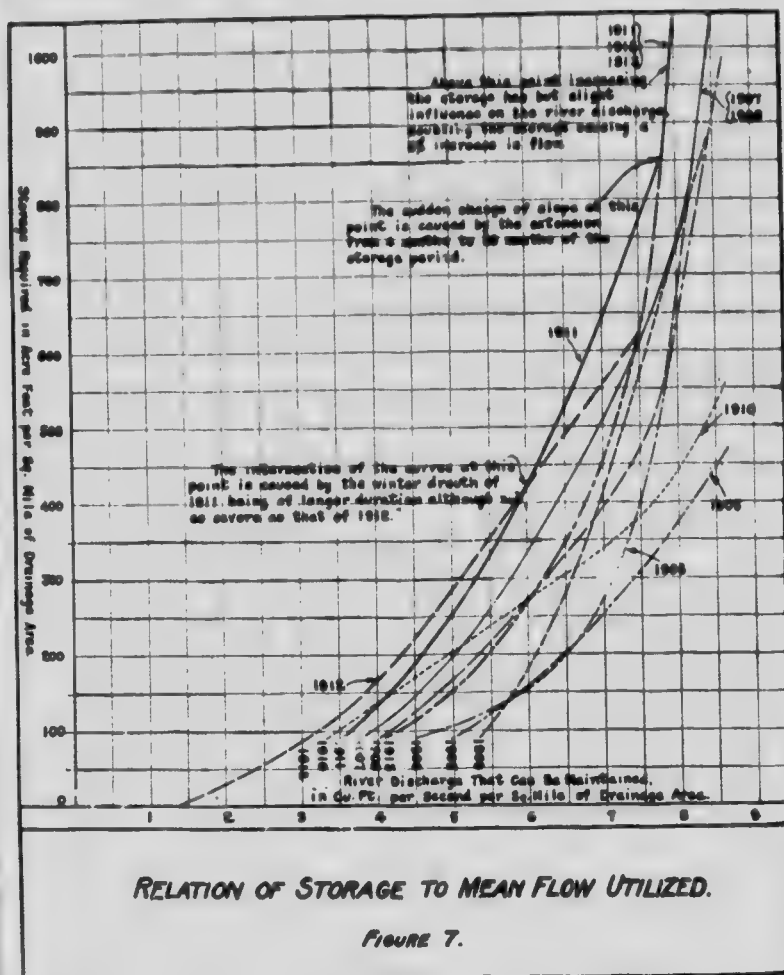
With the dam built to elevation 230 feet (79 ms.), a mean flow of 3,150 c.f.s. (90 cu. ms. sec.) could be utilized in the lowest years of record, and more than this in average years.



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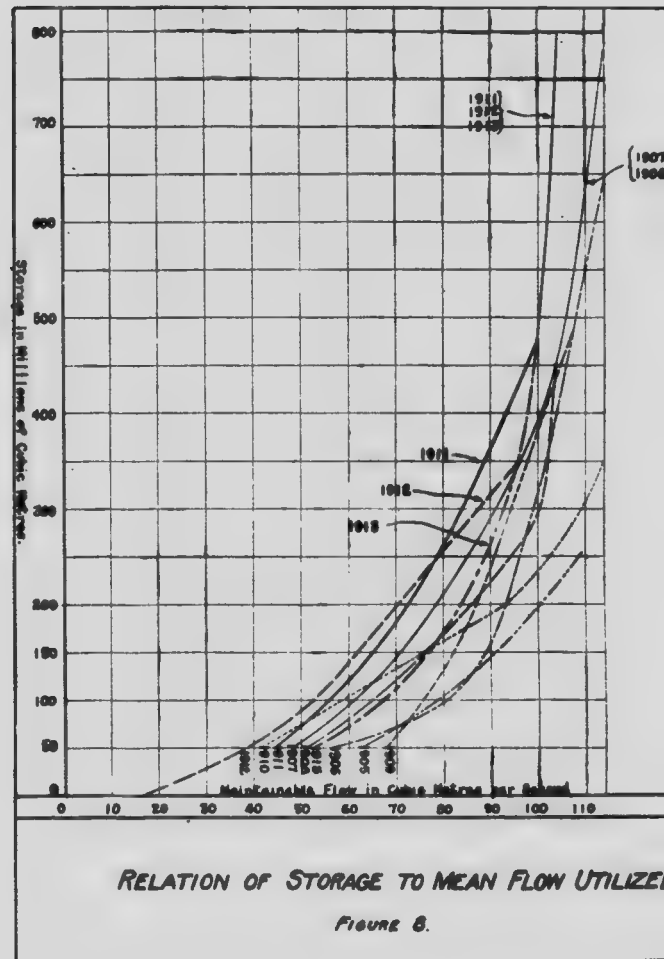
f for the year was
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e a dam built to
capacity of 370,000



Available Power.—With water in the reservoir at a mean elevation of 225 ft. (77.4 ms.), there is a total fall to tidewater of 250 ft., and if the whole of this fall could be utilized 80,000 horse-power could be developed continuously with the available mean flow of 3,400 c.f.s.

Allowance must be made, however, for the backing tailwater of the lower plant when the Fraser River is in flood; also for variation in level between the tailrace of

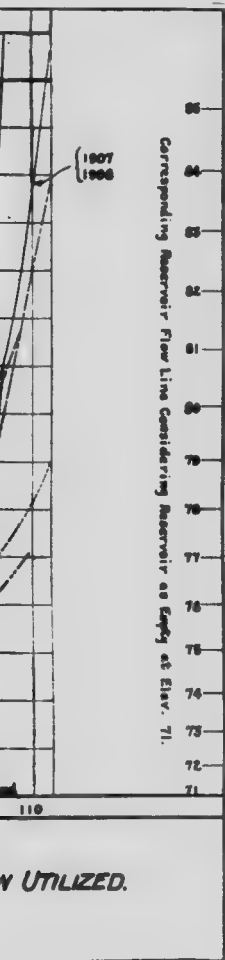


and the head water of the lower plant. Consequently head available for the full development must be taken a

With this fall fully developed, a maximum demand of 90,000 kw. on a load factor of 55 per cent. can be supplied.

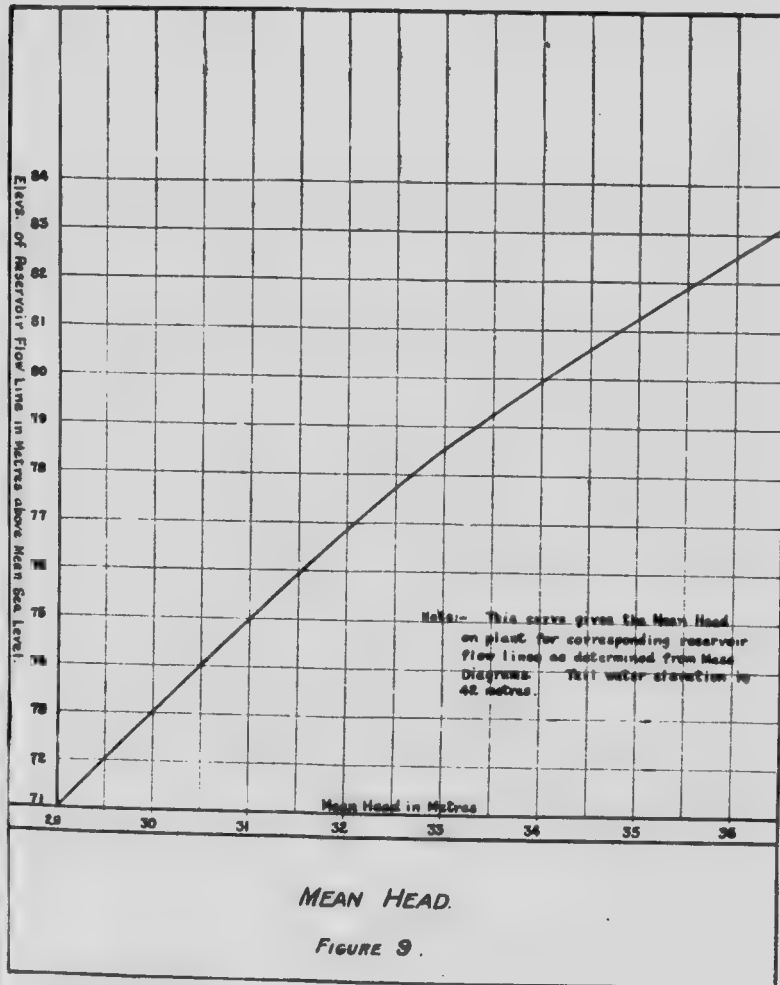
For the present the flow line of the reservoir will not rise above elevation 230 (78.9 m.), and as the tailrace of the u

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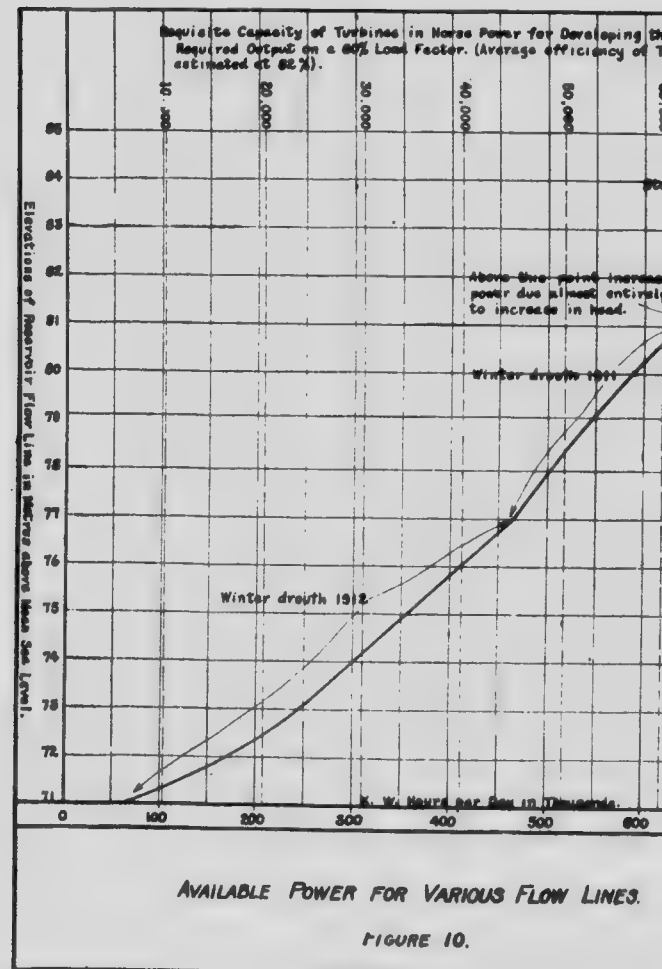
is fixed at elevation 110 feet (42.4 ms.), there is a maximum head of 120 feet and a mean head of 110 feet (33 ms.) at the upper plant. Under these conditions a mean flow of 3,150 c.f.s. (90 c.m.s.) can be utilized, and a maximum demand of 40,000 kw. on a load factor of 55 per cent. can be supplied.



By increasing the height of the dams to store water to a flow line at elevation 240 ft. (82 ms.)—3,500 c.f.s. (100 c.m.s.) could be utilized on a mean head of 118 ft. (36 ms.), which would give a maximum capacity of 47,000 kw. on 55 per cent. load factor.

Figure 9 is a diagram showing the mean heads of house for any given flow line of reservoir, as determined by mass diagrams.

Figure 10 is a diagram showing the mean kilowatt day that could be generated at the upper plant for any line of reservoir. This curve is computed from the cur

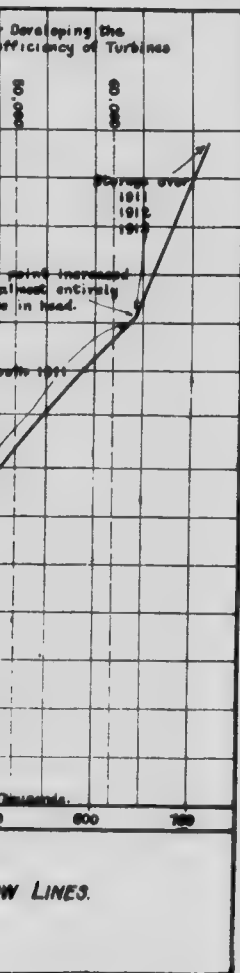


head, Fig. 9, and the curve of mean available flow, Fig. 9, overall efficiency of 78 per cent. being taken.

For the use of the power house operators a diagram, not reproduced here, has been prepared, showing the c

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each foot or meter in depth of the reservoir for generating kilowatt hours.

Determination of Economic Height of Dam.—The physical conditions at Stave Falls are such that consideration of cost alone would prevent the building of the dams to elevation 270 ft. (91 ms.). This would increase the reservoir to such an extent as to average low water years with high, so that a mean of 4,000 c.f.s. (113 cu. ms. per sec.) could be utilized. The total head available would also be increased from 225 to 255 feet (68 to 78 ms.), and the full development could be increased from 90,000 to 117,000 kw. at 55% load factor.

But the cost of making this addition to the existing works would be over \$1,500,000 for the dams alone, and besides this there would be expenditures for the purchase of additional submerged lands; so that the cost of obtaining the additional 27,000 kw. would be nearly \$60 per kw., exclusive of penstocks and power house.

For this, or for any other similar development, a curve showing the cost of the dams for various heights can be worked out, and by referring this curve to the curve showing available mean flow, and mean head for any given flow line—(Figs. 7, 8 and 9), a curve showing cost per kilowatt for the additional power obtained by adding to the height of the dams, can readily be plotted, and the most economical development can be determined.

For Stave Falls, a flow line at elevation 235 ft. (80.5 ms.) is the most economical development.

Only a small part of the information regarding the water supply of the Stave River given in this paper was available in 1909, when the present plant was designed; consequently the selection of the best elevation for the flow line of the reservoir was largely a matter of judgment.

In October, 1909, it was decided to take elevation 230 ft. (78.9 ms.) as the flow line, to acquire all the land round the margin of the lake lying below the 240 ft. (82 m.) contour, and to design the plant for a mean flow of 3,000 c.f.s. (85 c.m.s.).

The plant has been designed and constructed on this basis.

The Power House Site.—The topography in the immediate vicinity of the present development is shown in Fig. 11. In its natural state the river divided into two branches about 400 feet above the falls, the two branches uniting half a mile downstream to form an island. An ancient channel known as the Blind Slough, is shown to the north and east of the falls.

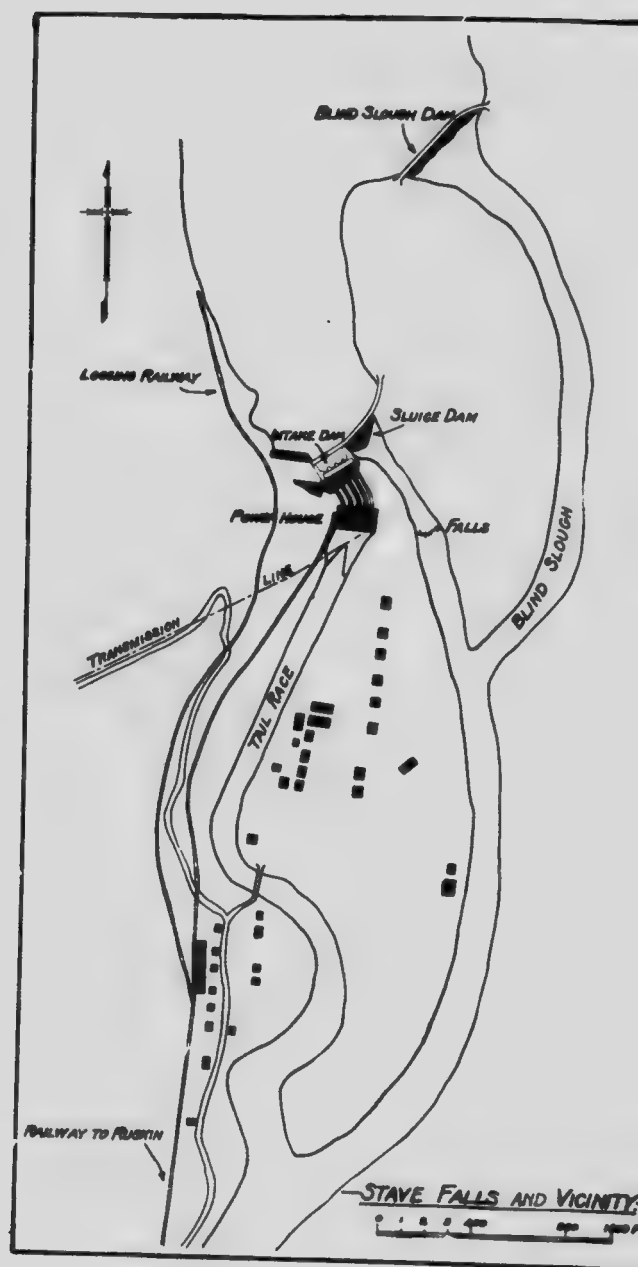
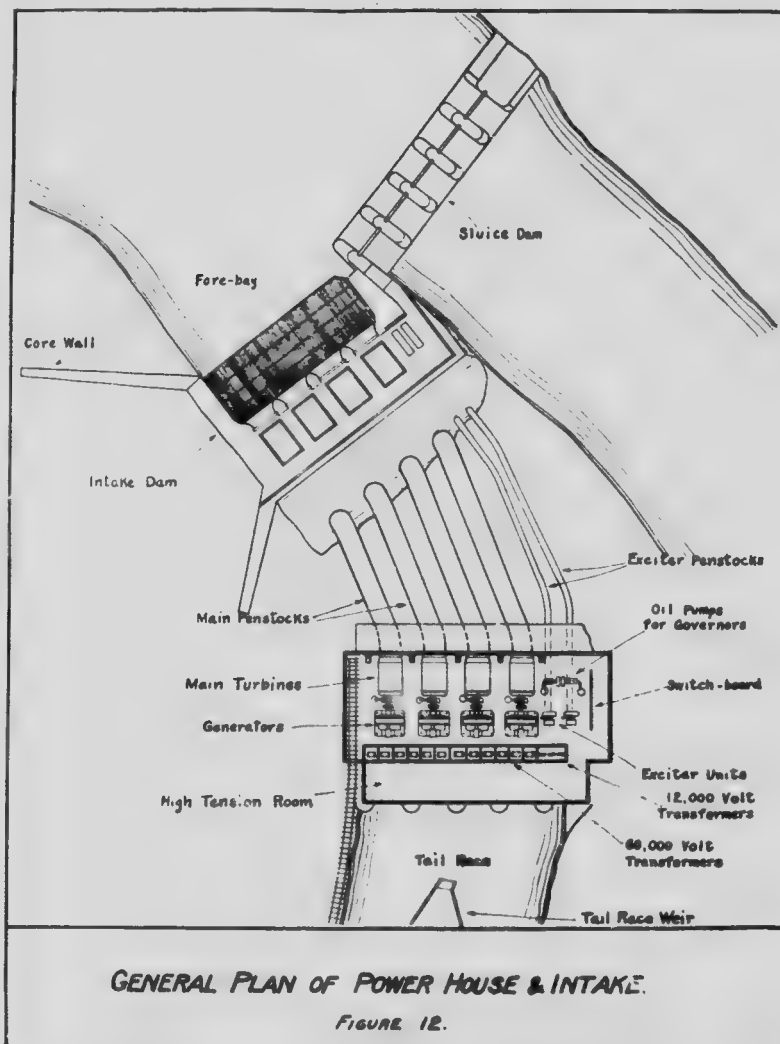


Fig. 11.—Topography at Power House Site, Stave Falls

The valley of the Stave is bounded by a mountain of granite on the east side, and from this mountain a low spur of rock extends across the Blind Slough and the north end of the island, forming the ridge over which the river falls.



On the west side of the river this rock spur takes a sudden dip where it abuts against a bench of glacial silts and clays which forms the western boundary of the valley at this point.

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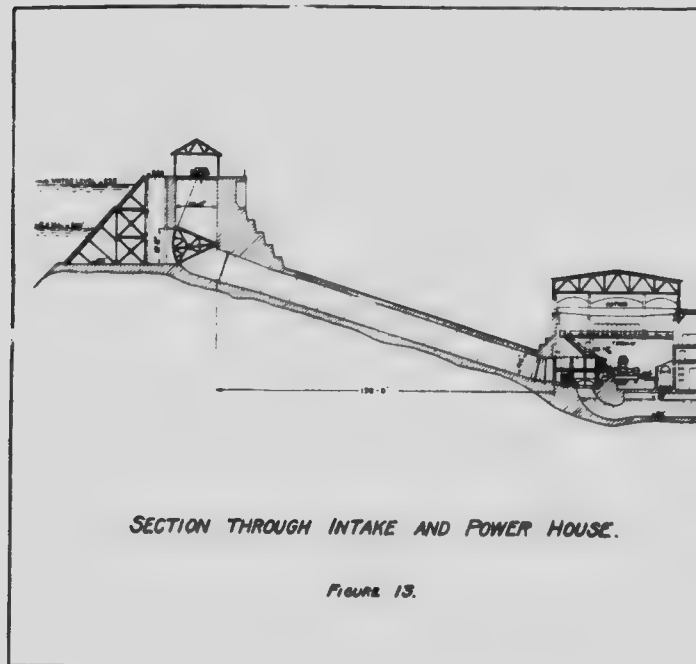
Stave Falls.

At the north end of the island the rock at the bottom of the river lies at elevation 170 ft. (60.7 ms.), and both channels are about 120 feet (36 ms.) wide.

In the Blind Slough the rock bottom lies at elevation 170 ft. (67 ms.) for fifty feet of the width, and between 200 and 210 ft. (70 and 73 ms.) for 400 ft. (120 ms.) of the width.

The engineers of the Stave Lake Power Company, planning a flow line at elevation 207 ft. (72 ms.), selected the west channel for the intake dam and power house, and the east channel for a sluice dam to control the floods, which was nearly completed by the summer of 1909.

When the Western Canada Power Company, Limited, took over the property and decided to build for a flow line at elevation 230 ft. (79 ms.) they adhered to the location of the intake dam and



power house in the west channel, but selected the Blind Slough for a permanent flood control dam.

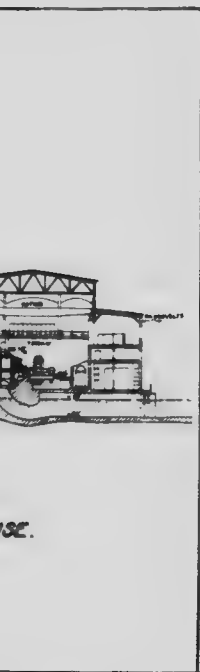
As it was important to keep the initial development as small as possible, it was decided to commence operations with a flow line at elevation 210 ft. (73 ms.) and to add to the height of the dam as additional power was required, retaining the sluice dam

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east channel for flood discharge until the flow line should be raised to above elevation 220 feet (76 ms.), after which the sluice dam would be built up solid.

From the foot of the falls in the west channel, where the powerhouse is located, to the south end of the island where the west channel rejoins the main stream, there is a fall of 60 feet (18 ms.). To have taken advantage of the whole of this fall would have involved very great expense for tailrace excavation or penstocks over 1,500 feet (450 ms.) long. It was therefore decided to locate the powerhouse in a rock excavation at the foot of the falls, and to excavate the west channel to a sufficient depth to form a tailrace with water at elevation 110 ft. (42.4 ms.).

With this location the penstocks are not more than 150 feet (45 ms.) long; thus giving almost ideal conditions for regulation of speed, a point of the very first importance where turbines have to meet the fluctuating demands of a general power supply.

The Hydraulic Generators.—The hydraulic condition governing the choice of turbine units may be summarized as follows:—

Maximum Head—reservoir full.....	120 ft.	36 ms.
Mean Head	110 "	33 "
Minimum Head—reservoir empty ...	100 "	30 "
Maximum variation in tailrace level	2.5 "	75 c.m.s.
Maximum velocity of water in penstocks	8 ft. p. sec.	2.4 ms. p. sec.
Mean flow to be utilized for generating power	3,000 c.f.s.	85 c.m.s.
Maximum flow to be utilized for generating power	5,000 c.f.s.	141 c.m.s.

The power house was laid out for four turbines, each to develop 13,000 brake h.p. under mean head; with a penstock 14'6" (4.42 ms.) diam.

The general arrangement of the plant is shown in plan and elevation in Figs. 12 and 13.

The turbine chosen as most suitable to fill all the conditions, was of the double horizontal Francis type, with central discharge, running at a speed of 225 r.p.m., and enclosed in a cylindrical flume with penstock connected axially. The volute casing was considered but not adopted, on account of the great cost of building such a casing for so large a volume of water.

Had this plant been designed three or four years later the vertical type of single runner Francis wheel would, without doubt,

have been adopted, not only on account of its higher efficiency but because it would have made possible a very material saving in the cost of the power house.

The turbines were built by the Escher Wyss Company, Zurich, Switzerland. They are shown in cross section in Fig. 14. It will be noticed that there is no intermediate bearing, the shaft (14.2 inches in diam.) being stiff enough to need no support.

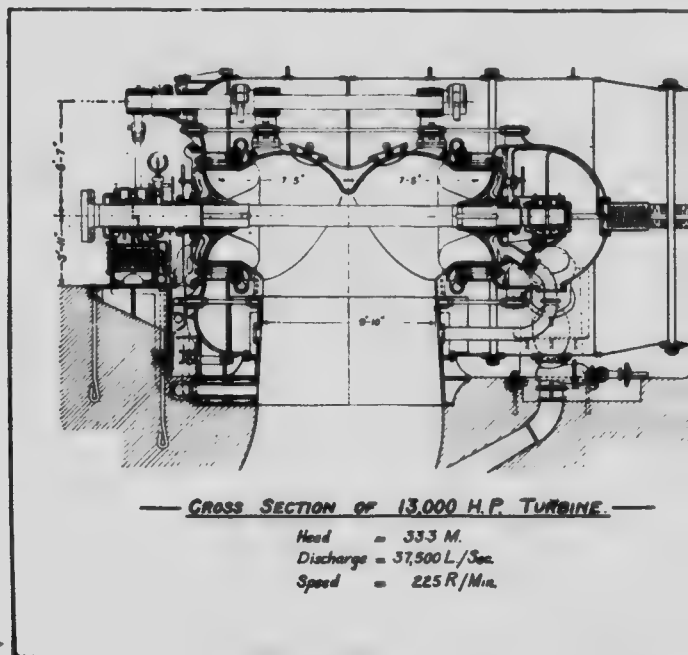


Fig. 14.—Cross Section of 13,000 H.P. Turbine.

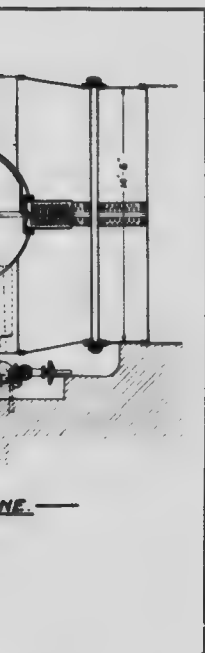
tween the outer bearings, thus removing the obstruction of the middle bearing to the discharge of the water in the draft tube.

The casing is 18 ft. in diameter and built of $\frac{3}{4}$ -in. steel plates with very heavy forged steel flanges. It is divided vertically along a horizontal diameter, to admit of easy erection and repair.

The end plate of the casing is of cast steel designed to stand a total thrust of nearly 1,000 tons which may come when the governor suddenly shuts the gates, under full head. The runners are 63 inches (160 cms.) diam., and the blades are steel plates cast into cast steel hubs. The bearings are oil-cooled, the larger one being 15 $\frac{3}{4}$ inches (40 cms.) diameter.

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The draft tubes are built in concrete to a carefully designed expanding section commencing with a circle 10' 8" diam., and ending in a rectangle 9' 5" x 21' 9". The velocity of the water when the turbine is discharging 1,300 c.f.s. is reduced gradually from 14.6 ft. per sec. at the top of the draft tube to 6.3 ft per second at its outlet.

The governor is of the Escher Wyss hydraulic type operating with oil under a pressure of 300 lbs. per sq. inch (21 kilog. per sq. cm.). The oil is supplied from a central pumping plant through a ring pipe system.

There are two high pressure three throw oil pumps each operated by an impulse wheel. Each pump takes its water from either exciter pipe and is capable of supplying all four turbines. The pump runs continuously discharging oil through a relief valve into the suction tank when oil is not being taken by the governors, and maintaining a receiver two-thirds full of oil and one-third full of air under pressure ready to provide for sudden large movements of the governors.

These governors are very sensitive and very sure in their action, and acting on a turbine which has so short a penstock and a flywheel provided by the rotor of the dynamo which weights 65 tons, they give very satisfactory regulation.

The exciters are driven by two 500 h.p. single runner Francis wheels, with volute cases—taking their water from two 46 inch steel penstocks.

The turbines were built on a guarantee of 83 per cent. efficiency at full load and 110 ft. head. Under 107 ft. head they have developed 10,000 kw. of electric power.

Electrical Equipment.—As this paper deals with the hydraulic features of the Stave River development, a brief description of the electrical equipment will be sufficient here.

The generators, exciters and transformers were built by the Canadian General Electric Company.

The generators are 3-phase, 60-cycle, 4,400-volt machines rated at 8,825 k.v.a., with 40 deg. cent., and 11,031 k.v.a. with 55 deg. cent. temperature rise.

There are two exciters of 250 kw. capacity each. There are twelve 3,000 kw. water-cooled oil-insulated transformers arranged in three banks to step up from 4,400 to 60,000 volts.

The switchboards consist of 60,000, 4,000 and 12,000-volt oil switch equipment, with a vertical panel control board, and were made by the Canadian Westinghouse Company.

Power House Building.—The power house is a reinforced concrete building which when completed for four units will be 165 feet long by 70 feet wide, with a 14-foot extension at the east end for the control board, and a 28-foot two story lean-to along the side for the switches and busbars.

The foundations were excavated in solid rock, a total of 47,000 cu. yds. being removed by skip and cableway.

Up to the main floor of the turbines the foundations are built of mass concrete with steel rail reinforcement over the tailrace arches.

The superstructure consists of a light steel frame, enclosed in reinforced concrete. The transformers are housed in individual concrete vaults accessible to the travelling crane from the top.

A feature of the design of the power house is the ample space around all the machinery, every part of which, including the transformers, are directly under the 60-ton travelling crane which spans the main building.

The 60,000-volt switches and busbars are contained in the lower story of the lean-to building, and all switches and busbars are separated by reinforced concrete barriers which were poured in place.

The 4,000-volt switches are contained in the room above the 60,000-volt apparatus, and the lightning arresters are carried on the roof.

Tailrace.—The tailrace channel was excavated by steam shovel in the old river bed. It is 70 feet wide and 1,500 feet long. About 75,000 cu. yds. of sand and clay overlain with heavy boulders, and 22,000 cu. yds. of rock were taken out.

Considerably greater fall could have been secured for the turbines by carrying the excavation deeper, but the quantities involved would have been too large.

As the tailrace discharges into a channel with a considerable fall, some provision was necessary to keep the tailwater at the power house at approximately constant level. For this purpose a low V-shaped concrete weir was built in the tailrace about 100 feet below the power house. The point of the V points to the power house, and the weir is 300 feet long. This provides for the full discharge of the four turbines with a range in height of the tailwater not exceeding 30 inches.

Penstocks.—The main penstocks are 14 ft. 6 in. (440 cm.) inside diameter. The upper ends which are embedded in the concrete of the intake dam are belled out to a diameter of 19 ft. (580 cms.). The maximum velocity of the water at the entrance of the

bellmouth is 4.6 ft. per sec. (1.4 m. per sec.), and in the penstocks it is 8 ft. per sec. (2.4 m. per sec.).

The penstocks were fabricated in a Vancouver shop, the plates being made in Scotland under rigid specifications and shipped to Vancouver via the Suez Canal. The plates at the upper end are $\frac{1}{2}$ -in. thick, and at the lower end $\frac{3}{4}$ -in. thick. The rings are 8 ft. wide, and formed of three sheets 16 ft. long.

The ring seams are double rivetted, longitudinal seams triple rivetted. All holes were punched $\frac{1}{16}$ -in. small, and reamed out after assembling in the shop.

Every alternate ring is stiffened by a $5" \times 5" \times \frac{1}{2}"$ angle rivetted to the outside. In the third and fourth penstocks each ring is stiffened by a $6" \times 4" \times \frac{1}{2}"$ angle.

For the greater part of the length the penstocks are supported in concrete up to the centre line, and at the entrance to the power house they are entirely enclosed in a heavy mass of concrete.

There are two separate 46-in. steel penstocks for the exciter and oil pumps.

Intake Dam.—The intake dam is a gravity section concrete dam founded on granite. It is 160 ft. long, and when finished to the full height will be 70 feet high. There are four main intakes separated from one another by piers 11 feet wide, projecting upstream from the face of the dam proper, and forming four gate chambers, 19 feet wide and 24 feet long. The gate chambers for the exciter pipes are set in the concrete dam to the east of the main gate chambers, and the water reaches them through a short tunnel in the concrete. Across the whole upstream side of the dam there is a screen 120 feet wide, set on a slope of 45 degrees.

The granite which forms the foundation of the dam, although jointed in all directions, is very impervious. There was only one place found where any water made its way through fissures in the rock, and this was easily taken care of by a 4-inch drain. The surface of the rock was excavated to a considerable depth, and a thoroughly good foundation with plenty of irregularities, to form security against sliding, was secured. As an additional precaution 2-inch steel rods, spaced five feet apart were set five feet deep all over the foundations. A further point of security lies in the arrangement of the rock abutments, between which the dam sets as a wedge.

The intake gates are of the radial type and were designed and built by the Escher Wyss Company. They close an opening approximately 20 feet square, the bottom sill of which will be 45 feet below the high water line when the dam is completed. The

gates weigh 23 tons each, and are operated by an electrically-driven winch, controlled from the power house switchboard. The water seal at the sides of the gates is made by segments built up of strips of oak, which are free to move laterally, so that the pressure of the water forces them against the sides of the gate chamber.

The gate chamber is necessarily large, and forms a very efficient entry to the penstocks, and the gate itself is easily operated.

For this dam the cost of radial gates was about the same as the cost of Stoney roller gates—but the radial gates involve considerably more cost in the structure of the intake, both on account of the length of gate chamber required, and of the added weight of masonry necessary to overcome uplift due to possible pressure of water below the gate chamber floor when the gate is closed. For this reason, the author would in future use Stoney gates in a similar situation, though where the radial gates can be installed without increasing the cost of structures, they are preferable.

In front of the gate chamber, stop log checks are provided for emergency or repair work.

The screens are supported on a combination of reinforced concrete piers and structural steel. They are not built so heavy as usual as ice never forms in the river, and so little drift gets to the screen that even in flood time attention is necessary only for a few minutes once or twice a day.

On the west side of the dam, where the rock abutment dips at a sharp angle, and is overlain with a heavy deposit of glacial meal, a core trench is to be sunk to a sufficient depth and filled with concrete, to ensure against any possibility of seepage along the contact between the rock and the glacial silts, when the water is raised to the higher levels.

Sluice Dam.—The sluice dam was the first piece of construction work undertaken by the Stave Lake Power Company. It was designed to take the whole flood discharge of the river, at a flow line too low to make the Blind Slough available for spillway. As the total length of the dam was only 150 feet, and as drift and huge logs had to be passed, an overflow dam was out of the question.

The sluice dam is of the same design as the Chaudière dam at Ottawa. It consists of reinforced concrete piers, 8 feet wide, with five sluice ways, 22 feet wide closed by stop logs. The stop logs are made of clear Douglas Fir—22 feet long x 16-inch x 24-inch; they are bolted together in pairs with a 5½-inch steel plate between them to give additional strength. They are raised and lowered by

means of an electrically-operated winch built to the same design as those in use at the Chaudière dam.

On the whole, the stop logs and the arrangements for handling them have proved satisfactory, for depths below the bridge not greater than 15 feet. For greater depths than this, it is difficult to remove the logs or to replace them so that they do not leak.

The stop log dam, when properly designed, is a very suitable and economical type of dam for regulating a reservoir or river for varying heights of flow-line, and at the same time providing for heavy flood discharge.

During the summer of 1913, the foundations were put in for raising the dam to its full height. In excavating for the new foundations, several pot holes were opened up, one of them forty feet deep, almost under the toe of the existing dam. This excavation gave a good indication of the water tightness of the rock, for although the bottom of the pot hole was nearly 80 feet below the water level, there was no sign of seepage.

The dam will be completed to its full height as a solid gravity dam of spillway type with a row of gates on top for partially controlling flood discharges, the majority of which will be taken care of at the Blind Slough dam.

Blind Slough Dam.—For a flow line at elevation 210 feet, the Blind Slough forms a natural rock spillway dam, 400 feet long with a channel 50 feet wide, and 20 feet deep at one side.

At the present time the channel is closed by a timber crib dam, which forms a temporary spillway 450 feet long at elevation 218.

The permanent dam will be a log sluice dam, with concrete piers, similar in general design to the existing sluice dam, but having two steel undersluices in the deep section.

Future Developments.—From the tailrace level of the existing plant to mean tide level at the mouth of the Stave River, there is a total fall of 134 feet. The daily range of the tide is about four feet. In June and July, when the Fraser River is in flood, the water may rise as much as 16 feet, though 12 feet is the usual maximum rise. During Stave River freshets, the water near the mouth of the river may rise several feet.

As freshets will nearly all be controlled by the dam at Stave Falls, and as the Fraser River floods affect the situation for less than two months in the year—it is feasible to design future developments to utilize a fall of 130 feet.

This could be developed in one plant by building a dam in the narrow gorge just above the mouth of the river, and driving a

2,000-foot tunnel for the penstocks. The dam would back the water up to the tailrace of the existing plant, forming a storage reservoir that would be large enough to hold a day's supply for the plant with a variation in head of less than 10 feet.

The dam would have a maximum height of 170 feet in a channel 100 feet wide, though outside of the channel it would not be more than 100 feet high.

While this development would be quite economical for the full capacity of plant, the initial cost would be high, as the dam alone would cost \$1,000,000.

As the full development will not be required for a number of years, and as it is important that expenditures on future construction shall not be made further in advance of actual demand than absolutely necessary, a plan is under consideration for the development in two plants, each operating under a head of 65 feet.

The lower canyon allows of a very economical development under this head, and a good site for the middle plant exists about two miles below Stave Falls.

Both these plants would be designed for single runner vertical turbines of from 10,000 to 12,000 h.p. capacity.

By the adoption of this plan of development, the Western Canada Power Company, Limited, can increase its plant capacity step by step, to keep pace with the demand for power, until it has installed a total of 120,000 h.p.

CONCLUSION.

The author has endeavoured to bring out the general principles that must be followed in the development of power from any important watershed, and would emphasize the following points:—

A.—That far the most important consideration in western development is the determination of the conditions governing the amount of storage capacity required for the economical development of the watershed.

B.—That until this determination has been made, no power plant plans can be intelligently laid out.

C.—That when this determination has been made it will nearly always be possible to lay out a progressive plan of development so that the unit cost of the initial plant does not bear too high a proportion to the unit cost of the complete development.

ACKNOWLEDGMENT.

The author wishes to acknowledge the help given in the design and construction of the plant by the members of the Western

Canada Power Company's engineering staff, viz.: Mr. A. R. Mackenzie, Resident Engineer on the construction of the dams; Mr. F. D. Nims, Electrical Engineer; Mr. W. R. Bonnycastle, in charge of designs of power house; Mr. G. A. Caherty, who was chiefly responsible for the compiling of the water records, and the designs of the extensions of the plant, and Mr. J. F. Cahan, Construction Engineer on the extension work.

The sluice dam was designed by Mr. William Kennedy, and the preliminary work done by the Stave Lake Power Company, was under the charge of Mr. J. C. Kennedy.



Fig. 15.—The Power House, showing two penstocks and tailrace weir.



Fig. 16.—The Power House and Tailrace.

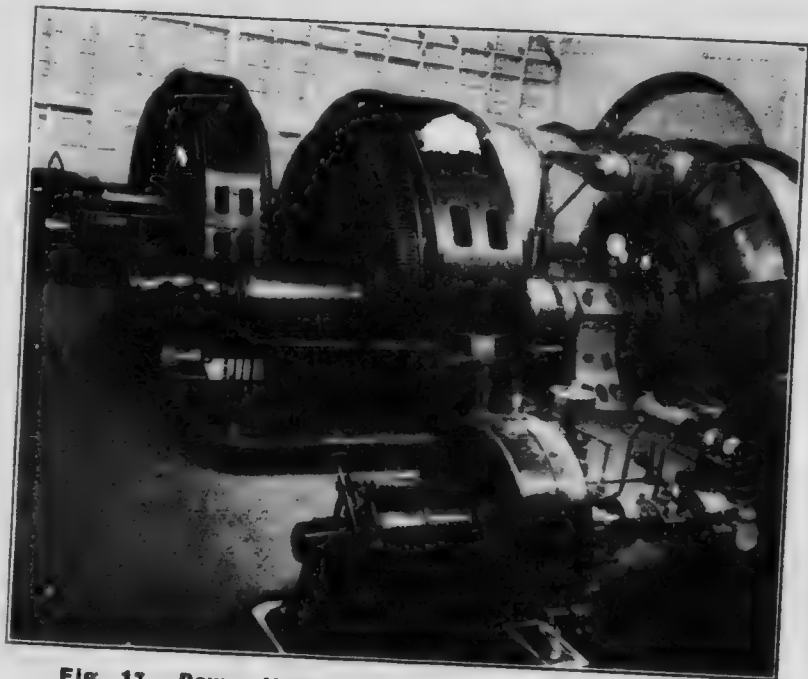


Fig. 17.—Power House interior, showing two turbines.



Fig. 18.—Power House interior, looking toward Switchboard Gallery.



Fig. 19.—A 30,000 cu. ft. per sec. flood passing through the Sluice Dam. Intake Dam in background.

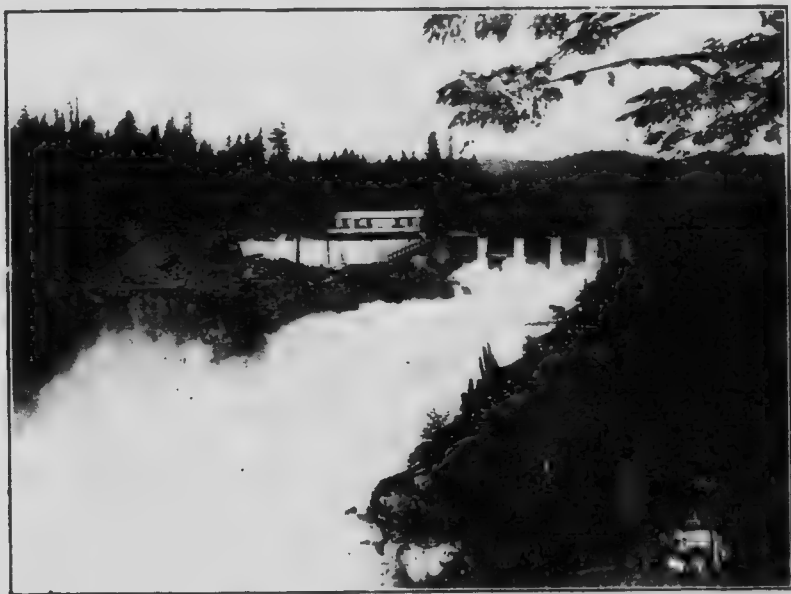


Fig. 20.—A 30,000 cu. ft. per sec. flood discharging through Sluice Dam and passing over Stave Falls.



Fig. 21.—Intake Dam on right—Sluice Dam on left. Water at elevation 210 ft.



Fig. 22.—Intake Dam in background—Sluice Dam in foreground. Water at Elevation 210 ft.



**Fig. 23.—Blind Slough Temporary Dam discharging water.
Top of Crib Dam at Elevation 218 ft.**



Fig. 24.—Blind Slough Dam Site and existing Crib Dam.



**Fig. 25.—The Canyon—site for lower development,
looking upstream.**



**Fig. 26.—The Canyon—site for lower development,
looking downstream.**

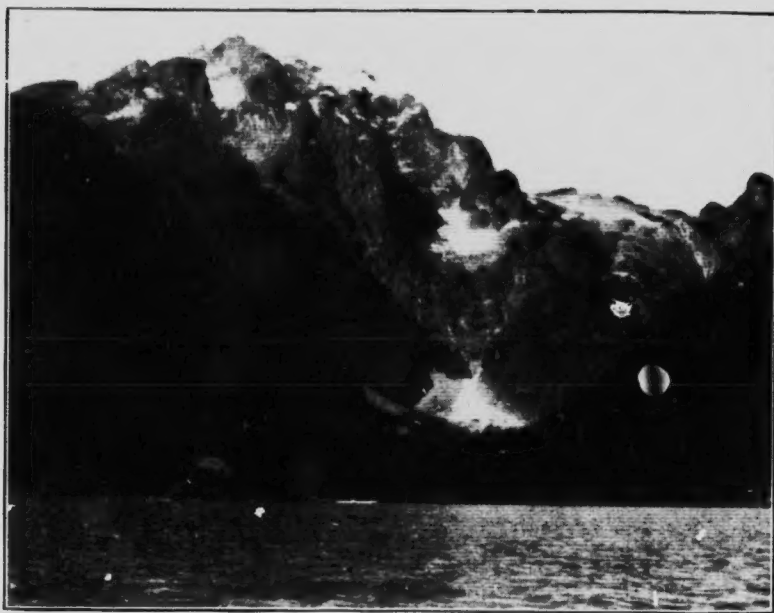


Fig. 27.—View of Mount Baldy from Stave Lake.



Fig. 28.—View of Stave Lake.



Fig. 23.—View looking upstream from Catthouse on Intake Dam.